ABSTRACT

To develop an embedment anchor to hold at 200 times its own weight of 25 lbs. extends the art of deep anchorings at small cost if a ballistic anchor containing a reciprocating mechanism can be materialized. Three general concepts are merged in one device:

1) about half the ultra high pressure energy released from a powder charge is used for ballistic penetration of the sea bottom.
2) a fraction of the balance of this energy is trapped at high working pressure and deepens the penetration by driving a simple, short-lived, reciprocating machine which executes less than 1000 cycles.
3) depletion of the trapped high pressure is finally downward at low pressure from the nose of the anchor so as to transport away bottom material which has been loosened by the action of the machine.

All main components are identified and dimensions are chosen to make these concepts compatible, and lead to a metal weight slightly in excess of the 25 lbs. goal. Performance of the embedment depends on details of the interaction between the anchor and local sea bottom and must be development tested. The mechanism with a very short-service life stroke should be inexpensive, but high temperature, high pressure seals for the brief duty are difficult and not known to be feasible.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

Page

TABLE OF CONTENTS (cont.)

I. Synopsis of central ideas in the proposal, and work statement in the proposal.

Sea-Space's original proposal (SSS-1184B, 17 May 1966) logically divides itself into three parts: goals for the main performance parameters of the anchor, a combination of features from several generalized concepts to be embodied in this anchor, and a work statement of five tasks. These three parts are taken up in turn below.

A. Goals for the main performance parameters of the anchor.

1. The ratio: Horizontal holding power (lb_f)/anchor weight (lb_f) was proposed to be 200/1. It was considered reasonable to set this value high as a design objective though a more conservative value appears more realistic.

2. The horizontal holding power was proposed to be 5, 000 lb_f. This value was chosen to reduce the cost and difficulty of the anchor development.

3. The target weight of the anchor follows immediately from the ratio given in (1) and the horizontal holding power given (2) above: $\frac{5,000 \text{ lbs.}}{200} = 25$ lbs.

B. A combination of features from several generalized concepts to be embodied in the anchor.

1. A ballistic phase of positive displacement and jet-propelled penetration of the ocean bottom.

a. The anchor to be driven downwards from a reactor which is restrained from moving upwards by the inertia of the ambient water.

b. The grain of the explosive charge to be tailored for the flattest possible pressure-time characteristic, to maximize the useful work done against the resistance of the sea bottom.

c. Trapping of part of the products of combustion behind a check valve within the anchor, at high pressure to supply the energy for

   (i) a vibratory deepening of the penetration, in which a mechanism within the anchor is driven off the stored high-pressure supply of gas, and executes between 200 and 800 power strokes before this storage is exhausted;

   (ii) downward jetting from the nose of the anchor of the exhaust gases from the performance of the mechanism above, to soften, lubricate and transport away the sea bottom material fragmented during the vibratory deepening of the penetration.

d. Safe-ing of the apparatus while it is on deck by precluding ignition except in the submerged condition.

e. Relaxation of mechanical tolerances and fits in the interest of reduced cost and increased reliability, in view of the short total service life of the moving parts (200-800 strokes).

f. The relation to a paving breaker or jack hammer to the anchor and the distinction from these well-known tools.

C. The Proposed Work Statement: 5 Tasks

1. Design and build 2 experimental models.
2. Conduct development tests in tanks filled with representative bottom materials.
3. Fabricate 2 prototype models andone set of recovery hardware.
4. Deliver and supply engineering liaison for customer test.
5. Bi-monthly and final reports.

II. Synopsis of central ideas in the contract, and work statement of the contract.

The contract as awarded (Goverment Contract No. BNy-62225, notice of award of Part I, dated 28 June 1966, was a simpler statement of fewer ideas than had been set forth in the proposal out of which the contract arose. The prototype anchors were deferred until a Part II which was not awarded, and Part I called only for two experimental pulse jet anchors to be designed, fabricated, assembled and tested.

Mechanics: The multi-phase release of energy principle was to be incorporated in the design in the interest of control, versatility and safety.

Criteria: The holding power was to be 5,000 lb_f and the weight goal was set at 25 lbs., not to exceed 40 lbs., but it was not clearly spelled out what was meant by the "weight".

Goals: The goals were generalized into a functional definition, the deep penetration of a deep bottom, and the depth of bottom of interest was set at 6,000 ft.

Testing: The tests were to be carried out in two substances: sand and cohesive soil.

A. Ideas which have stood up under study and evaluation.

1. Multi-phase release of energy. Investigation has shown that an improved embedment anchor could result from a device which offers more regulation for deepening the embedment than that possible from a single ballistic

burst. There are at least three possibilities for machines to deepen the embedment under more regulated conditions.

a. a rotating machine which would screw itself deeper into the bottom by means of inclined fins.

b. a machine to fire a sequence of small ballistic pulses, each independently ignited to give a downward power stroke without paying the weight penalties associated with containing large bodies of high pressure gas.

c. a simple positive displacement machine to hammer the bottom, break it up and transport the fragmented material upward by means of jetting.

In the performance of a rifle or cannon less than half (about 44%) of the energy content of the powder comes to be converted into muzzle velocity of the bullet, and most of the balance is in heat and pressure in the gases behind the bullet which are finally lost. Since the positive displacement of a small anchor can only be a few feet (the separation stroke in Sea-Space's rough design is 20 inches) it is a sound idea to trap a portion of the heat and pressure energy which would otherwise be wasted at the end of the positive displacement, and drive the machine from the trapped source.

2. Forward jetting of exhaust gases. Secondly, it is a sound idea to assist and regulate embedment by introducing some fluid into the sea bottom just below the nose of the anchor, and the exhaust gases from the machine suggest themselves as this fluid. The weakness of this program is that the machine must run off the pressure difference between the inside and the outside of the anchor, and is thus penalized by the hydrostatic pressure of deep anchorings.

B. Ideas which were too hopeful.

1. Reciprocating machine. Sea-Space has pursued the reciprocating machine concept which is dimensionally set forth below, to run between the trapped pressure of the products of combustion and the hydrostatic pressure of the sea. Such a machine is not wholly without precedent; in a sense certain automatic rifles are gas-driven reciprocating engines which run off the products of a powder charge. There are, however, very difficult development problems connected with the sliding seals at high temperature and pressure. The rough design set forth below requires 4 such seals on a 1.6-inch diameter, 3 on a 2.7-inch diameter, and 1 on a 3-inch diameter. This last seal executes a single sliding stroke(the separation stroke) but the others execute a stroke with each reciprocation of the

machine, that is they have a duty of a few hundred cycles.

The specification of these seals is peculiar:

a. Temperature, not less than 1000° R

b. Pressure, not less than 20,000 psi

c. Short service, of a few hundred cycles

d. Relatively large leakage is permissible in an anchoring.

Sea-Space has not been successful in identifying a developed seal to meet this specification, and the development of such a seal would thus become the pacing item in the anchor development set forth below.

2. The relation between the internal mechanics of the anchor and the soil mechanics of the sea bottom.

There are two important parts of the Sea-Space anchor which cannot be satisfyingly designed without there being carried out a test program: the tapered plug which varies the throat area of the upper nozzle, and the orifices which define the velocities downward and upward for the inertial reciprocator. The taper of the plug is to be required to match the constant supply of gas from the burning charge to the increasing demand for gas from the accelerating anchor by governing the rate at which the excess production is expelled overboard through the upper nozzle. At the beginning of burning a large excess is expelled, and the taper must be chosen so that at the end of burning the nozzle no longer expells a significant mass and all of the gas production is matched to the final velocity of the anchor. This velocity can be estimated to lie in the range 100-500 ft/sec, but a more accurate estimate depends on the unknown resistance to penetration of the sea bottom. Secondly, during the phase of reciprocating deepening of the embedment, as explained in more detail below, downward progression of the anchor as a whole depends very sensitively on the values of the coefficients of static and kinetic friction between anchor and bottom material. A fluid model of the bottom, which drags proportionally to the velocity squared, is unsatisfactory because the upward displacement of the anchor must be stopped by static friction, while the downward displacement is permitted by the smaller resistance of kinetic friction. The present studies, in the absence of tests of this mode of embedment, are unable to choose the orifices (and velocities) of the downward and upward strokes of the inertial reciprocater. In the absence of test data the feasibility of the reciprocating mode of embedment is open to question.

III. Ballistic Anchors

A. The State-of-the-Present-Art

Sea-Space has conducted a thorough patent search to uncover principles of embedment anchorings which have suggested themselves to inventors since the beginning of the century. Applicable patents are summarized in what follows. Embedment anchors in general come out of either of two main concepts: (1) slow chemical reactions, at low temperature and low pressure, are used to drive a simple machine to dig or screw the anchor into the sea bottom, (2) fast chemical reactions, at high temperature and pressure, are used to propell the anchor ballistically into the sea bottom. The performance of an anchor arising from either concept depends importantly on the details of the soil mechanics of the sea bottom, of which simple analytical models have been constructed but little experimental information has been accumulated.

1. Ballistic penetration. An anchor which weighs about 25 lbs. can be estimated to fill a volume space envelope of about 200 $in.^3$ (about 100 $in.^3$ of metal and 100 $in.^3$ of void space inside the envelope). If the slenderness of the space envelope is about $L/D = 10$ the envelope will be about 3 inches in diameter by 30 inches long, and this is roughly the size and shape which have commended themselves to ballistic anchor concepts. By

exploding a powder charge of about 1 lb. (specific energy of 300, 000 ft-lb) it should be possible to get a force of about 50, 000 lbs. working through 2 feet of the anchor's 30-inch length, to transform about 100, 000 ft-lbs. of the powder's energy into kinetic energy of the anchor motion. If the motion of the anchor were entirely unopposed, the resulting final velocity of the anchor would be about 500 ft/sec. This figure may therefore be taken as an estimated upper limit of the bottom-penetrating velocity which can be achieved by a small anchor which is purely ballistic in action. In fact, underwater drag forces will oppose the motion of the anchor and dissipate a larger fraction of the energy in the powder so that less than 500 ft/sec will be actually achieved. This velocity may be grasped physically as the velocity achieved by a freely falling body which has been dropped to the surface of the earth from an altitude of 4, 000 ft. Without reckoning the details of the soil mechanical resistance to penetration it can be immediately sensed that the depth of penetration is limited to a few feet rather than to tens of feet. It is, therefore, seen that there are very strong inducements for trying to increase this few feet of depth of penetration which can be achieved by a purely ballistic anchor.

2. Keying to provide holding power. All anchors depend in some way on presenting a larger effective sectional area to withdrawal than they do to insertion, and patent drawings invariably draw attention to some scheme for presenting this enlarged section against withdrawal. Very successful land anchors have been driven by auxiliary equipment and subsequently enlarged by explosion beneath the surface, the deformed sub-surface metal becoming an armature into which some cementing agent is extruded to fill the exploded hole. For the self-energized anchor of the present studies, the usual expedients have been to attach the anchoring cable to the anchor off-center along the length of the anchor. Withdrawing forces are thus applied so that they must key the anchor sideways and require it to present its largest sectional area against withdrawal. To stabilize the downward motion of the anchor during embedment fins are usually added over a large part of the length; these have the advantage that they can be made to present further sectional area against withdrawal.

3. Devices to avoid fouling the cable in the anchor. One of the causes of bad anchoring in the sea bottom is that the anchor flukes happen to become fouled in the chain with the result that withdrawal forces are applied to the anchor in an improper

direction, and much ingenuity has been expended in devices to prevent this happening. This question is very far downstream in the development of a truly novel anchor, as in the present studies, and does not arise in the case of an explosive anchor detonated by the contact of a trigger in its nose with the sea bottom.

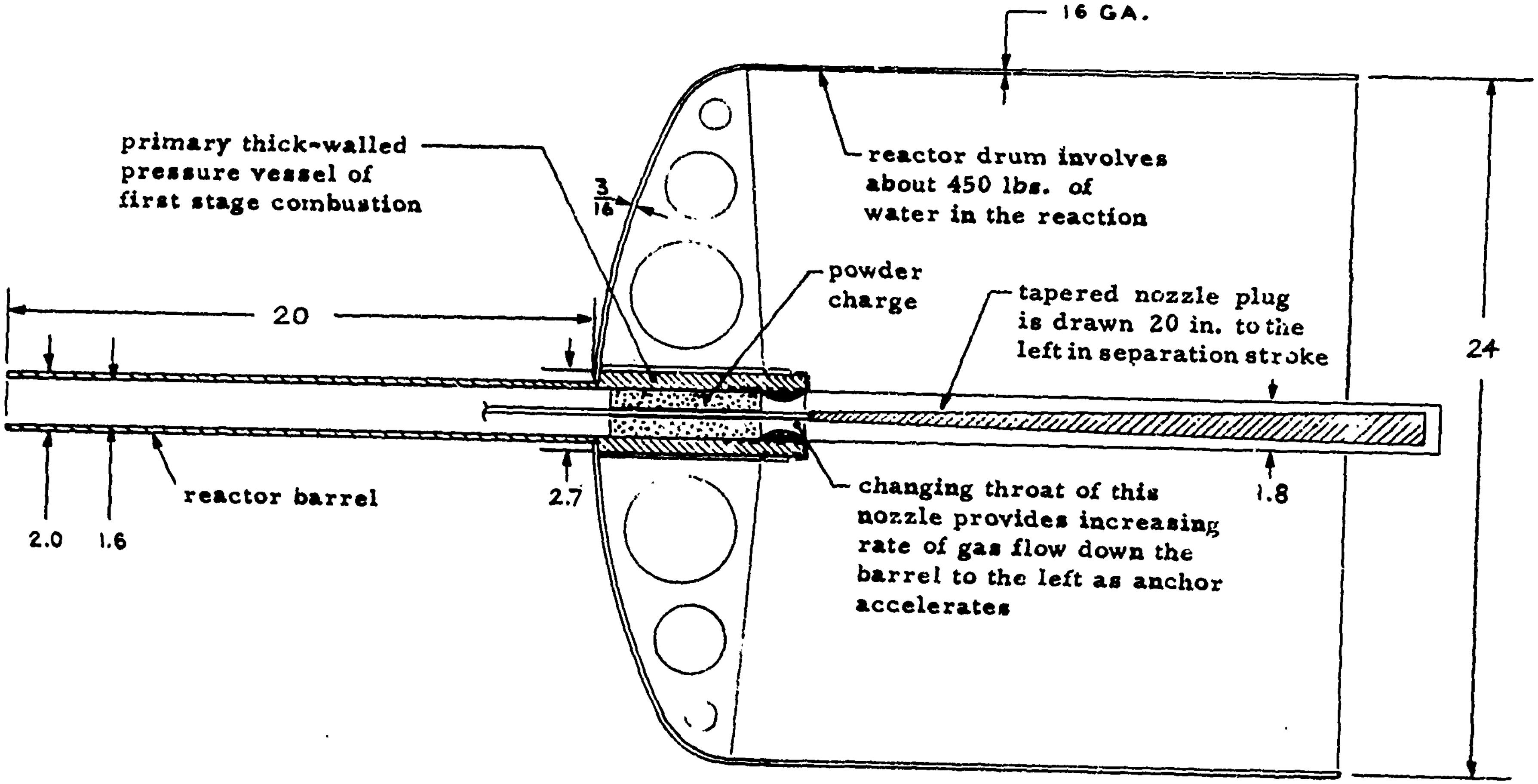
B. Description of pulse-jet embedment anchor concept

1. Nomenclature for Pulse-Jet Embedment Anchor

Each component of the presently described anchor system has been assigned a two-word or three-word title, as descriptive as possible of the function which that component provides in the system. The meanings of these short names are not always self-evident, but it is practically necessary in setting the anchor forth to use the short form over and over. Accordingly, in the following short dictionary these names are ranked and classified according to the functions of the components they name, and each is elucidated more fully than is convenient at any place in the body of the present text. It is noticed that the main classification is into two parts of the system which play the roles of a gun and its bullet: a reactor in which a charge is fired, which moves as a whole but does not contain any moving parts, and an anchor which is fired out of the reactor and subsequently becomes a simple positive displacement machine.

a. Reactor: (see Figure 1)

Mass drag reactor. This part is armed with an explosive charge and fitted with the anchor in preparation for an anchoring. At ignition the anchor is expelled downwards from this platform into the sea bottom, while a portion of the charge is expelled upward to form a high-pressure bubble, there being



MASS DRAG REACTOR

scale: 3/16" = 1"

Figure 1

aroused a downward thrust (of pressure and momentum) which opposes the undesired upward displacement of the platform.

1) Reactor breech. Analogous to the breech of a rifle this is a pressure cylinder, good to 100,000 psi against the micro-second peak pressure at ignition. (I. D. = 1.6, O. D. = 2.7, 5 inches long, weighing 5.3 lbs.) This breech contains the powder charge; lower end closure is by the anchor to be expelled, upper end closure is by the obturator nozzle (see below) which permits a tailored fraction of the products of combustion to be expelled upwards.

2) Reactor barrel. Analogous to the barrel of a rifle, this is a thinner-walled extension downwards of the breech which never sees the micro-second peak pressure at ignition. (I. D. = 1.6, O. D. = 2.0, 20 inches long, weighing 6.4 lb.) The anchor performs the 20-inch separation stroke down the 20-inch length of this barrel.

3) Obturator nozzle. Upward expulsion of part of the products of combustion is through this nozzle, which is unplugged at the beginning of the separation stroke, but is continuously closing as the stroke is executed by the tapered nozzle plug (see below) being drawn down into the nozzle by the descending anchor so as to occlude the sectional area of the nozzle throat.

4) Tapered nozzle plug. The taper of this plug is chosen so that as the anchor is accelerated downward in the separation stroke the mass flow rate upward and overboard through the nozzle is reduced. An increasingly larger fraction of the evolved gases of combustion is thus available to the increasingly larger chamber of the reactor barrel, (see above); the grain burns and the anchor is expelled at constant pressure. The design taper of the plug must thus be matched ultimately to the resistance offered by the sea bottom to acceleration of the anchor.

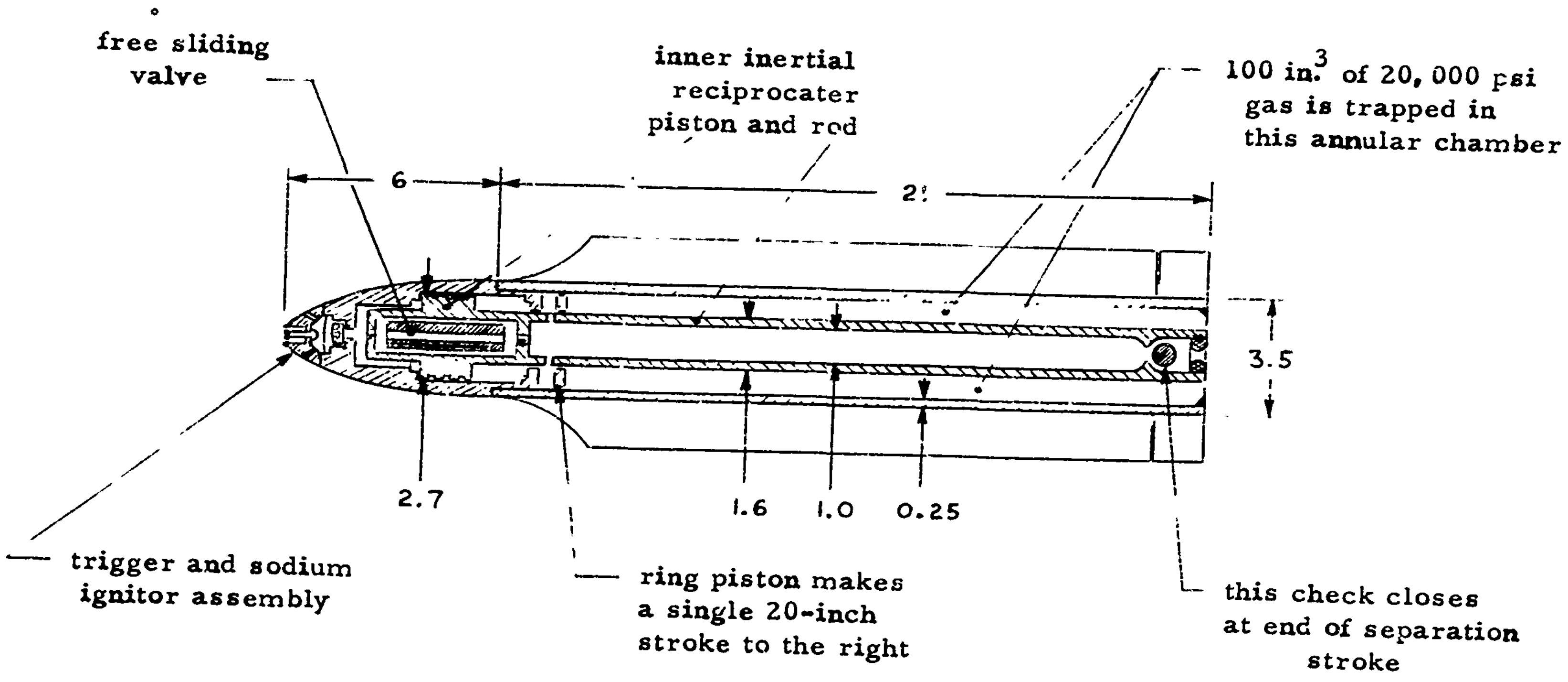
5) Fracture barrel. This barrel encloses the tapered plug during anchor lowering and seals the grain beneath the nozzle against wetting by the sea. It is a cylinder under external hydrostatic pressure (I.D. = 1.6, O.D. = 1.8, 20 inches long, weighing 3.2 lbs.) which fractures under internal pressure at ignition of the system and is blown away.

6) Reactor drum. This is a standard ellipsoidal dished pressure vessel head (O.D. = 24 by 3/16-inch thick, weighing 36 lbs.), with an 18-inch skirt which is rigidly secured to the reactor breech (see above) by four, five or six radial gussets (weighing 11 lbs. with lightening holes). The function of this component is to involve about 7 cubic feet of sea water with a virtual mass of about 450 lbs. in the reaction against downward anchor penetration of the sea bottom, then receive

the downward pressure forces of the bubble blown above the dish. The rigidity of this component must thus be commensurable with that of the bottom penetrated, and the reactor can be fitted with a lighter dished head when soft bottoms are penetrated.

b. Anchor: (see Figure 2)

Ballistic Embedding Anchor. This part consists of three main components: a main structural body which penetrates the sea bottom, an inner inertial reciprocater which executes a short stroke with respect to the body, and an innermost free sliding valve which executes a shorter stroke with respect to the reciprocater and governs the stroke of the latter. As it is expelled from the mass drag reactor, the anchor comes to contain a charge of the expulsion gases, and at the conclusion of the separation stroke between reactor and anchor this charge of gas is trapped and sealed into the anchor at about 20, 000 psi. This charge of gas is then distributed by the valve to drive the reciprocater up and down, and exhausted forward from the anchor nose to break up the sea bottom in front of the advancing anchor. The motion persists for a few hundred strokes until the pressure of the gaseous charge has fallen to the level of the local hydrostatic pressure, and there are thus more embedding strokes executed in shallow water anchorings.



BALLISTIC EMBEDDING ANCHOR

scale: 3/16" = 1"

Figure 2

1) Main structural body. This part consists of nose, pressure shell and fins, and weighs altogether 32 lbs. The frontal area presented to embedment is 10 in^2.

a) Nose. The nose is at O. D. = 3. 5 by 6 inches long and has exactly the diameter and contour of a 90 mm. armor-piercing shell. At its tip, the nose consists of a sodium ignitor assembly and the associated fuse, and has jetting ports through which gases are exhausted forward.

b) Pressure shell. This is a rearward extension of the nose, (O. D. = 3. 5 by 20 inches long, wall 0. 25 in., weighing 15 lb.). Containing gases at 20, 000 psi, this shell would be stressed to 140, 000 psi which is a reasonable working stress in high strength steel for the underwater application. At its lower end the pressure shell is closed by the upper stop for the inertial reciprocater, and at its upper end closure is finally made at the end of the separation stroke between reactor and anchor by the ring piston (see below) seating and sealing itself against a soft metal stop.

c) Fins. These are welded to the outside of the pressure shell to prevent the anchor body from wandering from the vertical path of downward embedment. Details of these fins are significant to the holding power of the anchor after embedment and keying: fins weighing about 4 lbs. can give the keyed anchor a projected area against extraction of 150 $in.^2$, which is 15 to 1 on the frontal area presented to embedment.

2) Inner inertial reciprocater. This is the fundamental moving part of the positive displacement machine in the anchor; it is essentially a piston and its rod. In the reciprocating stroke the piston (O.D. = 2.7 in.) is displaced 1.6 in. and sweeps a volume of 6 $in.^3$ inside the nose of the anchor. At the bottom of each stroke the piston strikes the bottom of its cylinder in the nose: these impacts cause the downward embedment of the anchor as a whole. Impact also throws the free sliding valve (see below) against its lower seat which new position of the valve initiates the return stroke of the reciprocater. The rod (O.D. = 1.6 in.) is guided and sealed both beneath and above the piston: the downward extension of the rod bottoms in the anchor nose on the first downward stroke and swages closed the soft orifice through which the ignition fuse was admitted to the system from the ignitor assembly. The upward extension of the rod runs the length of the anchor and is mated 20 inches into the female of the reactor barrel in preparation for an anchoring. It is thus this reciprocater rod which is fired out of the reactor breech at ignition and down the reactor barrel during the evolution of gases.

a) Upstream choking check valve. The rod is hollow (I. D. = 1 in.) and there is a check valve in its upper end across which the flow down into the rod is choked. The reduced pressure downstream of this check is felt through radial ports beneath the ring piston (see below) at approximately 20, 000 psi; as each of these ports chokes another one is uncovered by the separation stroke so that the flow rate into the annular chamber is continuously increased to maintain the pressure at 20, 000 psi as the chamber enlarges.

b) Downstream choking nozzle. At the lower end of the hollow rod there is a second choking nozzle across which the flow is always critical. The throat of this nozzle being chosen smaller than that of the upstream nozzle above, the flow down the interior of the rod is required to distribute itself radially outward into the 20, 000 psi annular chamber, where it does work at this pressure throughout the separation stroke, and is sealed off at separation in a 20, 000 psi reservoir having a capacity of about 100 $in.^3$

c) Lower swage plug. On the first downward stroke of the rod (see above) the lower end of the rod bottoms in the anchor nose and there is swaged closed a soft opening at its bottom end. Thereafter the lower end of the inner inertial reciprocater is sealed, and it becomes the casing within which the free sliding valve (see next item) oscillates up and down under inertial forces.

3) Free sliding valve. This innermost component of the embedding anchor is a reciprocating cylinder (O. D. = 1.4 by 4 inches long) in which radial ports are connected by admission and exhaust flow paths. The stroke of reciprocation is 1/2-inch; at one extreme of the stroke one set of radial ports performs the functions of admission and exhaust while a second set of ports is occluded by the wall of the chamber in the inner inertial reactor. At the other extreme of the stroke these sets of ports have exchanged roles so that admission and exhaust are interchanged. When the inertial reciprocater bottoms in the nose of the anchor, the free sliding valve is thrown downward by inertia forces to the bottom extreme of its stroke: the situation then is that admission is open from storage at 20, 000 psi through the downstream choking nozzle and free sliding valve to the underside of the piston, and the upward stroke accordingly begins. During this stroke the free sliding valve is held at the bottom of its stroke by inertia forces, and these forces throw the valve upward at the end of the upward stroke: the situation then is that exhaust is from the underside of the piston and admission to the upper side. It follows that by adjustment of one of the admission ports (which would have an assortment of orifices which could be

inset into it) the velocity of the downward stroke can be adjusted with respect to the velocity of the return stroke. This choice is crucial to the interaction of the anchor with various kinds of sea bottom, as explained below.

4) Ring piston. Fitted at assembly to the outside of the inertial reciprocater rod and to the inside of the pressure shell of the main structural body is a ring piston (O. D. = 3; I. D. = 1. 6 inches), which involves a sliding seal against both inside and outside surfaces. It is the function of this piston to contain the 20, 000 psi delivered radially from the inside of the rod during the separation stroke and to be finally stopped at the upper end of rod and shell when the stroke is finished and separation is complete. The escape to the sea of 100 $in.^3$ of 20, 000 psi gas is thus prevented by this stopped piston.

2. Low-weight containment of ultra-high pressure gases: staging of the separation stroke.

In the separation stroke the displacement downwards of the anchor relative to the reactor is about 20 inches and the stroke is accomplished in about 3-1/2 milli-seconds. It is the purpose of the design to provide the forces for this positive displacement by two stages of pressure:

a. A high-pressure stage (at about 60, 000 psi), supplied by the burning grain, within he reactor and working on the upper face of a small-bore shaft which sticks upwards about 20 inches from the anchor into the reactor. The moving boundary on which these high pressures work is thus an upper surface of the anchor as seen from the reactor.

b. A lower-pressure stage (at about 20,000 psi), supplied by the high-pressure stage, contained within the anchor and working on the lower face of a larger bore shaft which sticks downwards about 20 inches from the reactor into the anchor, concentrically enclosing the first-mentioned shaft. The moving boundary on which these pressures work is thus a lower surface of the reactor as seen from the anchor. It is arranged that at separation the gaseous contents of this stage are not exhausted but trapped in the anchor and become the reservoir at 20,000 psi off which the subsequent reciprocating embedment is driven.

There are several advantages accruing from this design concept, and also several difficulties to be overcome if it is to be practically embodied. These may be listed as follows:

c. Advantages

1) At the instant of ignition there is a pressure peak, a few micro-seconds long, which reaches perhaps 100,000 psi. These gases and peak pressures are experienced only by the reactor breech, which is thus the only part of the system which needs to be designed heavy and strong enough for this pressure

peak. Moreover, the massive part is associated with the reactor as it should be if it is the kinetic energy of the anchor which is the purpose of the ballistic phase.

2) Of the anchor, only the upper face of the shaft experiences 60,000 psi and all other parts may be designed for 20,000 psi or less, with reduction of the anchor weight.

3) The duty period of the reactor lasts only 3-1/2 mill-seconds and the high temperatures therein do not matter to its mechanical performance because there cannot be significant heat transfer to the metal in so short a time. Staging permits a body of water (as a heat sink) to be charged into the low pressure stage, so that the operating temperature of the 20,000 psi gases trapped in the anchor is reduced to about 1000°R, permitting the two- or three-minute duty which is mechanically required of the anchor.

d. Difficulties to be overcome

1) Provision of a constant pressure-time characteristic to both stages.

For either body, the reactor or the anchor, the equation of motion is of the form

$$F - D = ma$$

where F is the force associated with the gases and D is a drag associated with the sea water and the bubble above it for the reactor and with the sea bottom for the anchor. The drag terms are not known in either case, (they can be approximately modeled by making the drag forces to proportional to the first and second powers of the velocity) and the history of the relative velocity between reactor and anchor during the separation stroke can thus be only approximately estimated. Details of the grain design and the varying discharge upwards must thus wait until bottom penetrating experiments are performed.

3. Possibilities of performance of the mass drag reactor.

The mass drag reactor is isolated from the rest of the system and assigned rough dimensions in Figure 1. It consists of a mild steel ellipsoidal pressure vessel head ("dished head"), 24 inches in diameter by 3/16-inch thick, with an 18-inch skirt. The The shape of this head is to be preserved during the period that it exerts large forces against the sea by radial webs which are bolted or welded rigidly to the primary combustion chamber. This is a pressure vessel strong enough to contain the 60, 000-100, 000 psi peak pressures at shot start, but only large enough to contain thepowder charge.

In preparation for an anchoring, the powder charge is measured into the primary combustion chamber through a breech obturator nozzle at the upper end of the chamber and there protrudes upward from the chamber, through the nozzle, and partially obstructing the nozzle throat, a nozzle plug increasing in diameter upwards and having a length of 20 inches (which is the length of the separation stroke between ballistic anchor body and mass drag reactor). Both nozzle and plug are sealed against wetting by the sea by a fracture barrel, strong enough against buckling under the external hydrostatic forces of the sea, but weak enough to be blown apart by the much larger internal pressures of the gases released from the combustor through the nozzle in the first instant after ignition. There are in this instant four effects favorable to the anchoring (favorable to the ballistic penetration of the sea bottom) which arise from the arrangement set forth above, as follows.

a. Virtual mass of the sea. The mass of the metal parts listed above is commensurable with the mass of the ballistic anchor body at 40 lbs. In view of the fact that the separating explosion is purely internal to the system and in consideration of the conservation of linear momentum in the up-and-down direction, one has the first thought that the upward displacement of the mass drag reactor will be wastefully equal to the downward displacement of the ballistic anchor body, and will thus waste half of the energy released in burning. This thought is insufficient as follows. Owing to the dish-shape of the mass drag reactor and the incompressibility of the sea, any displacement of the dish upwards imparts upward momentum to the sea itself. (On the underside of the dish the pressures cannot be larger than the local vapor pressure of the water and cavitation will surely occur.) There is a virtual mass of the sea above the drum which is to be added to the contents of the drum in the momentum relation and the conservative opinion is that a hemisphere of water above the skirt should be allowed. If the dish is 24 inches in diameter, such a hemisphere of water weighs 135 lbs., and the ratio of masses between reactor and ballistic body is $\frac{300 + 135 + 40}{40} = 12$ Momentum being truly conserved therefore reduces the wasted upward velocity of the reactor less than 10% of the useful downward velocity of the ballistic body, in consideration of this single effect of the virtual mass of water involved in the reaction. It is a homespun example of the same phenomenon that a rifle shooter, accepting a "kick" against his shoulder when he pulls his trigger, involves his own body in the momentum relations and increases the muzzle velocity of the bullet.

b. Pressures over the upper surface of the dish. The effect set forth just above is amplified according to the following argument. At ignition there is the fast evolution of gas within the primary combustion chamber and a nearly vertical increase of the pressure of these gases to the range of 60, 000 to 100, 000 psi. The peak pressures instantaneously achieved are reduced (which permits reduction of the wall thickness and weight of the chamber) by the absence of upper end closure, and gases flow immediately up into the fracture barrel, which ruptures. There then remains an expanding bubble of high pressure gases above the dish, and in their work of expansion these gases are considered to cause a downward displacement of the dish. In the two-phase situation the flow process cannot be discussed analytically, but the gases released by rupture of the fracture barrel are at so much higher a pressure than the ambient hydrostatic that it is easiest to visualize the dish being pushed downward by rupture of the fracture barrel.

c. Jet propulsion effects. In the two-phase situation (gas and liquid) there is no way to say that a truly supersonic flow of the products of combustion will develop in the exit plane of the converging-diverging nozzle (Laval nozzle) in the obdurator at the upper end of the primary combustion chamber. But there is certainly some mass flow rate upward at this nozzle, at an average velocity, which means an upward efflux of momentum from the mass drag reactor when this is considered as a system. The mass drag reactor is thus a reaction motor experiencing a downward force from these effects

d. Gravitational effects. Finally, to complete the fourfold itemization of performance possibilities of the mass drag reactor, any downward motion it may have from the three effects listed above is gravitationally assisted, by a force which is known exactly, the weight of the anchor. The point is made explicit because the usual application of rocket power is along an upward trajectory and the gravitational force is subtractive, while in the present case the effect of this force is additive.

4. The sequence of performance which it is desired to achieve.

There are many points at which SSS has worked with ideas which offer potential improvements on anything that has hitherto been accomplished with embedment anchors. In pressing these ideas into a unified design one is forced to face their relationships among one another, in the manner of systems engineering, so as to get from the detailed design the most improved anchor which the present state-of-the-art can offer. These ideas are now set forth sequentially along the program of a single embedment operation, so that the necessary relations among them will become evident.

a. Safe-ing and fuzing the device. Any explosive anchor, prior to the execution of an anchoring operation, presents some of the hazards associated with a loaded deck gun which is not permanently secured to the deck. It is thus a point of the present design to make ignition of the powder charge depend on the anchor's being immersed, and this is done by supplying the heat for ignition of the fuze from the exothermic reaction between metallic sodium and water. Ignition of the fuze depends on the presence of water and thus on the anchor's being submerged, in which case a premature ignition of the explosive charge would no longer be hazardous to the anchoring crew. In general (as will be set forth below) certain parameters of the anchor for a particular embedment will be chosen and set (orifice sizes, powder charge) from a knowledge of the character of the local sea bottom, and these settings would probably be made on the day of the particular anchoring. Prior to that time the metal parts of the anchor would have an indefinite shelf life, wholly unarmed, lacking either powder charge or fuze, and would thus not be associated with the anchoring ship's magazines.

b. Detonation and ballistic phase. Two main parts of the system share in the functions of the ballistic phase: the ballistic body and the mass drag reactor. At shot start the propellant charge is held between these two main parts and one of the effects of the evolution of gas in the chamber is to separate the ballistic body from the mass drag reactor, there being a stroke about 20 inches long in which the male of the former is expelled from the female of the latter, much as a bullet is expelled from the barrel of a gun. A portion of the gas evolved is thus simply discharged into the ambient sea when the two members come apart at the end of the 20-inch stroke. A second portion of the gas evolved has been trapped behind a check valve into a receiver at 20, 000 psi within the ballistic body; at a later phase of the execution of embedment this receiver is to become a reservoir of high pressure gas off which the reciprocation of the ballistic body is to be powered. Finally, a third portion of the evolved gas is discharged upward through the vertically oriented Laval nozzle which faces aft in the mass drag reactor.

c. Transitional phase. After separation has occurred any residual burning in the mass drag reactor is simply wasted to the sea through the barrel downwards and the nozzle upward, and is without influence on the ballistic body. The ballistic body having penetrated about two feet into the sea bottom continues this penetration until the resistance of the bottom brings it to rest.

d. Reciprocating embedment phase: impact mode. The anchor's coming to rest must bring the inner inertial reciprocater and the innermost free-sliding valve downward against their bottom stops. In this position of the valve there is admitted from the reservoir at 20,000 psi a pressure 500 psi above that of ambient hydrostatic pressure on the underside of the piston and the reciprocater begins its return stroke under this pressure. Completing its return, the reciprocater is brought against its upper stop, which throws the valve against its upper stop. In the new position of the valve pressure is applied to the upper side of the piston and the power stroke begins. Choice of the admission orifice permits adjustment of the power in the power stroke, which ends at impact of the piston on its lower seat. There is a longitudinal wave transmitted through the anchor nose to the sea bottom, which is locally fragmented by the forces of this wave.

e. Reciprocating embedment phase: jetting mode. It is arranged that the exhaust gases from the reciprocations discussed above are conducted downward to the nose of the anchor and there jetted forward into the sea bottom. The effect there is uncertain; qualitatively these gases must transport away from the site of failure those elements of the bottom which have failed in the impact of the power strokes.

5. A short-lived machine to reciprocate and deepen the embedment.

Figure 3a shows the lower rod and rigidly connected piston of the

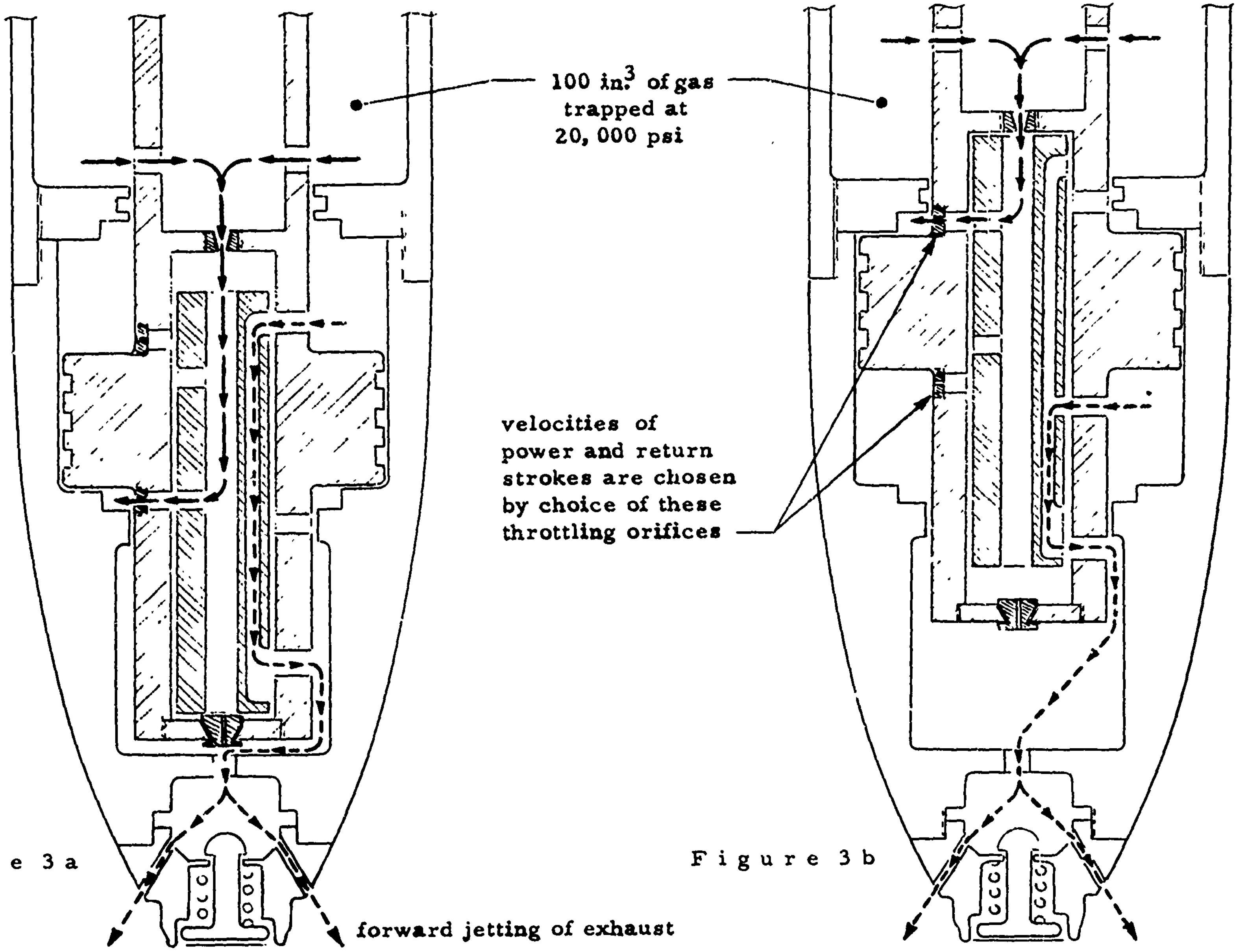


Figure 3a

START OF UP-STROKE

Figure 3b

START OF DOWN-STROKE

INTERACTION OF NOSE, PISTON AND VALVE

Figure 3

inner inertial reciprocator at the bottom of one of a sequence of power strokes into the nose of the anchor. The number of these strokes depends on the external hydrostatic pressure of the anchoring, but not very sensitively. If one anchors at 3000 ft. of sea water, the hydrostatic pressure is 1350 psi; at 6000 ft. it is 2700 psi, and there has been a 7% reduction of the pressure difference (20, 000-1, 350 = 18, 650 psi) which determines the number of strokes. At the bottom of its 1. 6-inch stroke the lower end of the rod of the reciprocater has struck the anvil in the anchor nose and the impact has two consequences: (1) a compression wave in the anchor nose is delivered to the material of the sea bottom to fragment this material locally; (2) the free sliding valve is thrown downward against its stop.

In this position of the free sliding valve the admission of gas is to the under face of the piston, along the flow path marked by solid arrows flying with the flow in Figure 3a, originating in the 20, 000 psi supply, throttled at the choking nozzle to a few hundred psi and finally admitted to the underside of the piston across an inset orifice in the radial port of the reciprocater rod. The diameter of this last orifice evidently governs the rate of gas admission for the return stroke, which can be executed as slowly as desired by the choice of a suitably small orifice. Secondly, in this position of the free sliding valve, the exhaust from above the piston is marked by dotted arrows flying with the flow along the free sliding valve and downward out of the nose of the anchor into the sea bottom. It is the function of this gaseous discharge to clear the fragmented bottom material and transport it upward along the outside of the anchor nose.

Figure 3b shows the same parts at the end of the return stroke. Pressure forces have driven the piston through its 1.6-inch stroke against its upper stop with the result that the free sliding valve is displaced upward through a 1/2-inch stroke against its upper stop. In this position of the valve, the admission of gas is to the upper face of the piston, along the flow path again marked with solid arrows flying with the flow, originating in the 20,000 psi supply and finally admitted above the piston across another inset orifice in the radial port of the reciprocater rod. This orifice will usually be chosen of larger diameter than the orifice which constricts the flow admitted to the return stroke, and the power stroke will thus be executed at larger accelerations of the reciprocater and larger kinetic energies finally delivered to the anchor at impact of the rod in the anchor nose.

C. The steps required to attain a pulse-jet design

1. Propellant grain

Sea-Space dealt with the research departments of the principal gunpowder manufacturers (Olin, Hercules, duPont) and chose a neutral burning (burning surface area per initial unit weight is essentially constant) formulation from Hercules, type 5250.60, web thickness: 0.053 in., grain size: 1/4 x 1/2 in. with 7 perforations. This powder should not be regarded as a final choice, but it appears to be the most suitable of powders in production, and the choice avoids all the complications of designing and casting a solid grain as is done in solid rocket applications.

2. Aerodynamics of the rearward expulsion through a varying throat.

The chamber receiving the gases evolved is enlarged during the separation stroke according to the relative velocity history between anchor and reactor, and if there is to be constant pressure burning it is required that the gas production to the chamber be increased along the separation stroke. This requirement can be met by a nozzle which dumps an excess production overboard at the beginning of burning, and is matched at the end of burning to the final relative velocity at separation. Since the propellant is chosen for a stable evolution of gas at constant pressure and temperature, the throat of this nozzle (the area A in the expression for the flow-rate across a supercritical nozzle) must be continuously reduced along the stroke. The only practical way to vary this throat area is with the taper plug of the present discussion. In development testing, the changing diameter of this plug must be matched to the equations of motion of anchor and reactor.

3. Storage and the reduced storage temperature.

With powder burning at 50-60, 000 psi for 3. 5 milliseconds the instantaneous gas temperatures achieved may range as high as 3000°R, and it can be estimated that the gas trapped at 20, 000 psi would be at an initial temperature (at the end of the separation stroke) in excess of 1500°R. This temperature is too high for the supply to the inertial reciprocater for several reasons:

a. unreliable operation of the seals which prevent the gas from escaping to the sea,

b. temperatures in excess of the metalurgical limit must, after heat transfer to the wall has taken place, weaken the wall and present the possibility of pressure failure,

c. heat transfer outward to the sea is energy irreversibly lost to the anchor and is thus not available to the embedment mechanics, and such heat transfer is driven by the high internal temperatures.

It is thus a correct strategy to provide the anchor internally with about 1 lb. of water to experience these temperatures. Heat transfer to this water at constant volume of the system converts the thermal energy of the trapped gases to pressure energy, in which form it is retained by the anchor if there are no leaks. The stored gases are reduced to a temperature of about 1000°R, which is acceptable to the metal, although not known to be tolerable to the seals. Before these gases are used to drive the reciprocater they are expanded across throttles to low pressure and temperature.

D. Weight Considerations.

A weight statement for the anchoring system under discussion is as follows:

Reactor

barrel	6.4 lbs.
combustor	6.3
dished head	36.0
skirt	23.0
gussets	11.0
nozzle	1.1
taper plug	1.2
fracture barrel	3.0
Total for metal of reactor	88.0 lbs.

Anchor

nose	12.1 lbs.
pressure shell	15.1
fins	4.0
reciprocater rod	8.6
reciprocater piston	1.7
sliding valve	1.0
ring piston	1.4
Total for metal of anchor	43.9 lbs.

The target weight for the anchor, as a matter of contract, was 25 lbs. not to exceed 40 lbs., and it is seen above that there is a small excess over the higher figure. A 10% weight adjustment downward can be accomplished if the major diameter of the anchor (shown at 3.5 in. in Figure 2) is reduced to 3.325 in. with other diameters proportionally reduced while the length remains unchanged.

This new dimension would not influence the holding power of the anchor through the planform if the tip-to-tip dimension of the fins remained unchanged, and it is not outspokenly clear that the depth of embedment would be reduced by the reduced pressure storage, in view of the increased slenderness of the penetrating body. But it is very doubtfully feasible to achieve the lower target weight of 25 lbs. in a first prototype incorporating all the mechanical ideas of the present discussion by simply scaling the characteristic radial dimension downward. After development testing of the moving parts to determine the small permanent deformations of these parts which can be permitted in an expendable machine with a short duty period it would probably be possible to realize some savings in the weight (about 12 lbs.) of these parts. However, 15 lbs. of the present anchor is in metal which does service as a pressure vessel, and the only way to reduce this weight is to accept a higher working stress in the metal.

For the reactor, it should be noticed that two-thirds of the 88-lb. figure stated is found in the skirt of the drum and the dished head which supports this skirt, and 12% in the gussets. These figures are very likely to be reduced in underwater development testing. As was pointed out above, the performance of this head and skirt during the 3.5-millisecond separation stroke is complex, probably involves the small compressibility of water and the propogation of compression waves in water and steel. It is certainly possible that testing would indicate that the 23-lb. skirt could be dispensed with entirely, and that the 24-inch dish could be reduced in diameter, the weight coming down from 36 lbs. with the square of the diameter.

E. Level and Tempo of Development Required.

A small ballistic anchor which deepens the initial ballistic embedment by subsequent mechanical action, and has been conceived above so as to avoid excessive unit costs in production, is not an easy undertaking as a matter of development and test. It is clear in the foregoing discussion that a working model, embodying the novel ideas of staging, mass drag reaction, entrapment of propulsion gas and frictional deepening of the embedment, cannot be immediately built in hardware. A step-wise, cut-and-try approach to the design of a working model is needed to close several important questions which remain open; there are two main steps:

1. A full-scale model of the anchor of Figure 2 should be fabricated:

    a. delete the following from the working model of the system.

        1) the trigger and sodium ignitor assembly, which is simply replaced by a blank in the nose with jetting orifices drilled into it

        2) the ring piston, which is simply replaced by a blanked closure of the upper end of the annular chamber with a low temperature sliding seal against the reciprocater rod

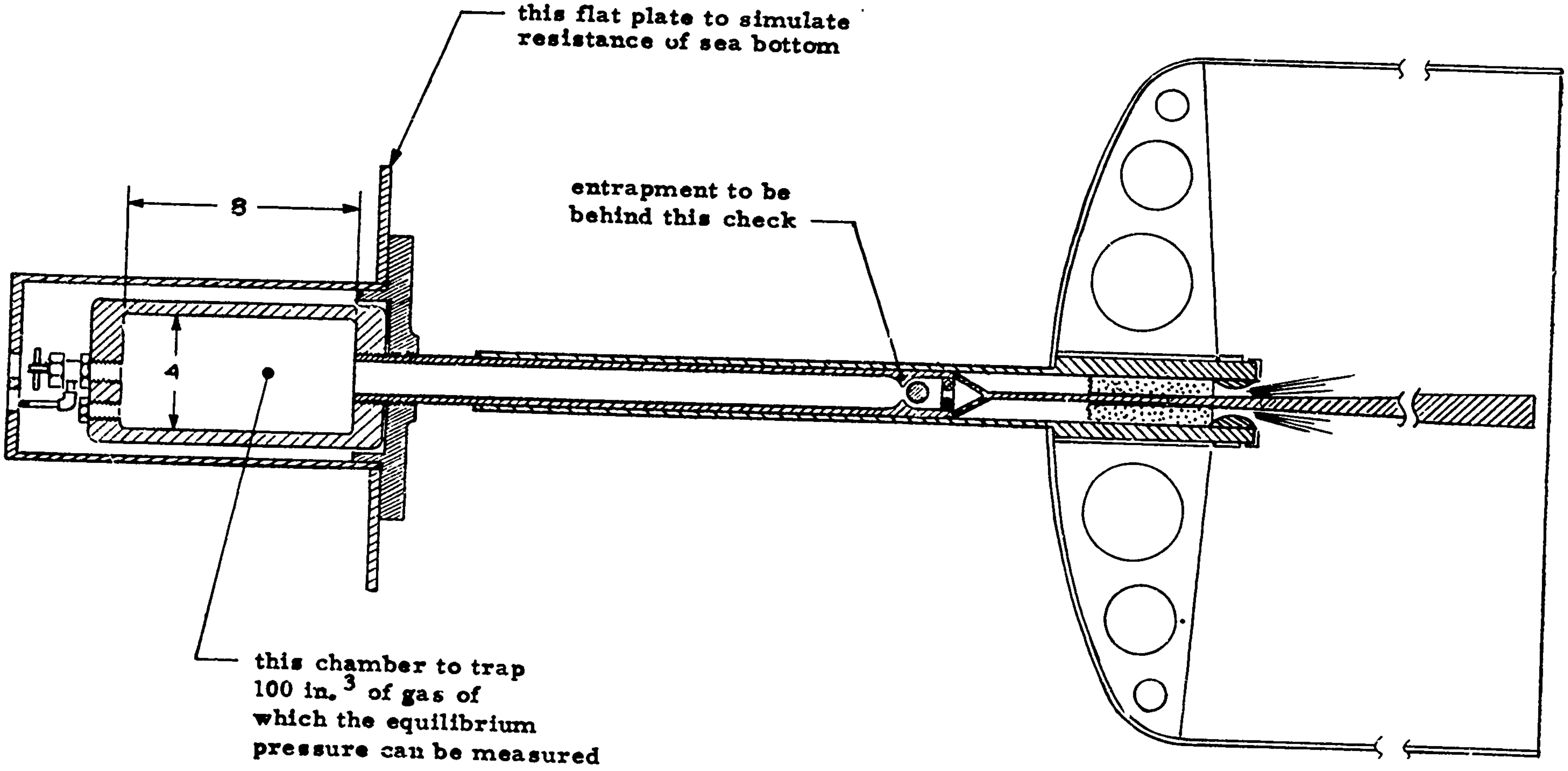
3) the check and nozzle in the upper end of the reciprocater rod.

b. make all parts of mild steel according to the dimensions of Figure 2, so that the inertial and dynamic relations among anchor, reciprocater and sliding valve will be tested.

c. supply the annular chamber with bottled air at room temperature in the range 500-1000 psi through a flexible hose connected into the blanked upper end of this chamber.

Unresolved questions of the embedding downward progression of the anchor can then be closed with this test model. It is convenient to vary the supply pressure off which the reciprocater is driven, and the penetration gained per stroke can be evaluated in sand and cohesive soil. It would thus be possible to determine in test whether the desired interaction between the anchor and the sea bottom can be achieved fairly cheaply: fabrication and test of such a model is estimated to be a six-months effort. It is a possibility that the results of this test are negative, and in this case the costly investigations of high pressure, high temperature seals and the mating of anchor and reactor as to interior ballistics are avoided. Pending a satisfactory outcome of this test, step 2 can be taken as follows.

2. A full-scale reactor and the mock anchor of Figure 4 should be fabricated and explosively tested underwater. The quantities to be varied from test to test would be the diameter



BALLISTIC TEST OF SEPARATION STROKE

scale: 3/16" = 1"

Figure 4

and drag of the anchor flat plate, the taper of the nozzle plug, and the initial charge of the propellant. The quantities to be measured would be the quantity of gas entrapped in the anchor and the displacements of anchor and reactor. It is estimated that about six explosions would be enough to map the joint performance of anchor and reactor in the ballistic phase. Again it would be a six months effort, accompanied by significant costs for development hardware and test instrumentation.

Pending an acceptable outcome of steps (1) and (2) the detailed engineering of a working model, in high strength steel and with high temperature, high pressure seals could begin. The present prospects for these seals are too uncertain to warrant money being spent on them until the performance of steps (1) and (2) is validated. The design of a seal which is to give 500 cycles of duty and then be valueless so that it can be cheaply expended necessarily involves cut-and-try experimentation, and it is estimated that a year would be required to meet this peculiar specification.

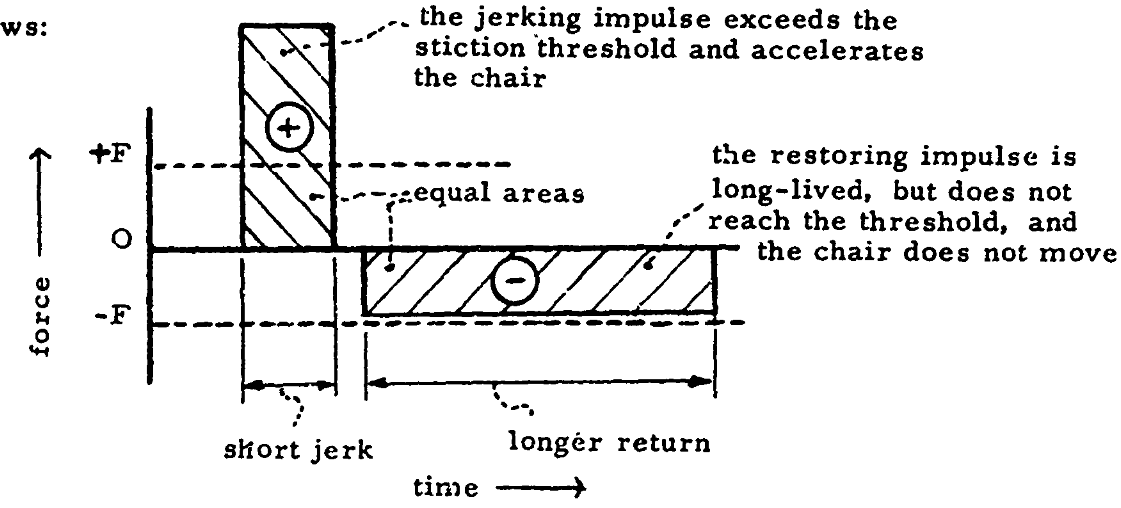
F. Cost Considerations.

The foregoing level and tempo of development required is believed to be realistic, and the direct inference is that a concurrent development of both anchor and reactor is unwise, and that there should be two successive six-months periods of development testing, followed by a year of engineering and fabrication of a pair of working models. It is seen that the cost of the development is in the neighborhood of $100, 000. The risks, as has been acknowledged above, are considerable, and it can be estimated that there is a 75% chance of passing each of the first two development steps of six months each and entering on the detailed engineering of the second year.

Unit cost of the end item, however, should certainly be small. Questions of the seals cannot drive the cost of the end item up because expensive seals, if found to be required, would terminate the development. There is nothing else intrinsically expensive in the system; it is difficult to conclude that unit cost of the end item could go above $1000 in view of the very short ballistic phase (3. 5 milliseconds) and the duty period thereafter of a few hundred strokes. More probably the unit cost for a production run of a few dozen anchors would be about $200.

Appendix i: The Locomotion of an Office Chair.

It is a fact that a person sitting in an office chair with casters on it can, without touching the floor with his feet, make a succession of jerkings of his body, and cause the chair to proceed across the floor in any desired direction. The locomotion is inefficient but real. If one considers the sitter together with his chair as a mechanical system, the mechanics of the net displacement of the center-of-mass of this system, without there having been applied any external force to it and without there having been any directional expulsion of mass from it, is not very easily understood. Understanding comes from consideration of the frictional forces inside the casters and between the casters and the floor. The sitter assumes some position of rest in the chair then suddenly applies muscular forces to the chair so as to achieve a second position of rest, laterally different from the first in the respect to the chair. In consideration of the absence of external forces on the sitter-chair system and the conservation at zero of the linear momentum of this system, there is on the chair, during the brief interval of the sitter's muscular exertion, a lateral impulse applied by him. The duration of the impulse on the chair is small but the force is large, being large enough to overcome the forces of static friction ("stiction") at bearing surfaces in the casters and between the casters and the floor. The chair is thus laterally accelerated, but the lateral motion is immediately opposed and amortized by forces of sliding and rolling friction which the motion arouses. Practically, the lateral motion dies out quickly and the lateral displacement of the chair is perhaps an inch or two. Having gained an inch for the system, the sitter returns from his second to his first position of rest in the chair, doing so cautiously rather than jerkily. The impulse he applies to the chair is opposite this time in sign to the first one, but extended in duration and accordingly much reduced in absolute force level. The force level is in fact so small that the threshold of stiction forces in the bearing surfaces is not achieved, and there is thus no return translation of the chair to annul the inch or two gained earlier in the sitter's jerking motion. In energy language, although the impulses applied by the sitter are equal in value and opposite in sign so that they satisfy the momentum relation, the jerking impulse is at high enough a force level to do work against dissipative forces, while the restorative impulse is at too low a force level to do work. Repeating the cycle set forth above the sitter is able to work his way across the floor, inch-wise against the forces of friction. The impulse diagram for a single cycle is as follows:



the jerking impulse exceeds the stiction threshold and accelerates the chair

equal areas

the restoring impulse is long-lived, but does not reach the threshold, and the chair does not move

Appendix ii: The Downward Progression of a Paving Breaker.

The downward progression of a paving breaker (of the kind one often sees in one's role as "sidewalk superintendent" of reconstructive operations in cement or concrete) also arises from motions which are purely internal to the machine, but is physically different from the locomotion of an office chair as that motion was set forth above. The airpowered machinery of a paving breaker may weigh 100 or 200 lbs; the small model with which SES experimented actually weighed 62 lbs. The jaws of this machine is fitted to the top of a steel shaft having a section of about 1 in.^2, and coming at its lower end (the working end) to a point or to a collection of pointed teeth. With the working tip of this shaft at rest on cement, and the massive machine rigidly mounted above it but not yet powered by air, static equilibrium requires the presence of compressive stresses in the cement to support the weight of the machine. It is seen that locally these stresses are in the amount of several thousands of psi, which is already commensurable with the crushing strength of small cement samples in compression. On air power being supplied at the hose, the arrangement of the machine is such that an anvil, rigidly held to the top of the working bar, is successively struck by a hammer (impact tool). There is set up a longitudinal compression wave in the steel which runs down the shaft and, on delivery at the working end, momentarily intensifies the local compressive stresses in the cement which fails locally. The paving breaker as a whole then gravitates into the failed material and finds a new static equilibrium of Newton's Third Law forces. A second blow is struck on the anvil above and the sequence continues, there being a downward displacement of a millimeter or an eighth of an inch at each stroke. It is seen that progression of the tool into the solid material depends partly on a high level of the static compressive stress induced by 1) the weight of the tool, 2) the small frontal area at the tip of the shaft over which this weight is distributed. The case is thus not closely analogous to that of the embedment anchor, which has a projected frontal area of perhaps 10 in.^{2} and a weight ideally of perhaps 50 lbs., leading to compressive stresses in the sea floor of a few psi, where several thousand psi were deduced above for the paving breaker.

Appendix iii: Depth Estimation and Holding Power.

There is a 30% variation in the densities of sands and soils, and a representative weight of these materials in air is 130 lbs. $/\text{ft.}^3$, which is twice the density of sea water. The effective weight of the material of the sea bottom can thus be taken as 65 lbs. per cubic foot of material which can be regarded as exerting a downward bearing force on the planform of the embedment. Secondly, the coefficient of internal friction μ (which is the tangent of the angle of repose) for sea bottom materials may be taken to range between 0. 25 and 0. 75 $(14 < \phi < 37^\circ)$. At the lower limit $(\phi = 14^\circ, \mu = \tan\phi = 0.25)$ the conical volume of material above an embedment of depth h is $\mathcal{V}_{\min} = 0.065h^2$ (with h in feet and $\mathcal{V}$ in ft.^3) while at the upper limit the volume is $\mathcal{V}_{\max} = 0.59h^2$. At 65 lbs. $/\text{ft.}^3$ for the bottom material, about 77 cubic feet of sea bottom should be bearing on the planform of the embedment to give a holding force of 5, 000 lbs., and this figure leads to embedment depths:

$$h_{\max} \text{ (associated with } \mathcal{V}_{\min}, \mu_{\min}) = 34 \text{ ft.}$$

$$h_{\min} \text{ (associated with } \mathcal{V}_{\max}, \mu_{\max}) = 11 \text{ ft.}$$

These depths are estimated for an anchor of zero planform and may be reduced 10% for the small anchor which presents a planform of about 1 ft.^2

Consider first the final depth of 11 ft. in a bottom material with large coefficient of static friction, $\mu = 0.75$. Because the forces of ballistic penetration are well above the frictional drag during the 20-inch separation stroke and continue to be large during the transition phase after separation, it is easy to visualize one half of the 11-foot penetration being accomplished ballistically. There remains 5-1/2 feet to be accomplished in reciprocating and jetting embedment, in say 500 power strokes. This requires a deepening of the embedment of 0.011 ft. = 1/8 inch per stroke, which is commensurable with the downward progression of an air-driven impact tool in sandstone, and it seems feasible that the anchor could achieve this rate.

The 34-foot penetration of a bottom with minimum friction ($\mu = 0.25$) is much less satisfyingly probable. If a 2-foot penetration is achieved before separation in 2 1/2 milliseconds and the downward velocity is then high, drags independent of friction will penalize this velocity and it is difficult to picture a transitional penetration to a depth of more than 10 feet. High velocity bullets do not penetrate water so much as this. There would then remain 24 feet to be achieved in 500 reciprocations at a rate of about 1/2-inch per stroke. Since the stroke of the reciprocater is less than 2 inches long, this requires a net displacement gain for the system of more than 25% of stroke, which is very doubtful in a medium offering small frictional resistance.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Sea-Space Systems, Inc.
Torrance, California 90501

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
INVESTIGATION OF EMBEDDING AN ANCHOR BY THE PULSE-JET PRINCIPLE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final 30 June 1966 - 2 October 1967

5. AUTHOR(S) *(Last name, first name, initial)*
Lair John C.

6. REPORT DATE
2 October 1967

7a. TOTAL NO OF PAGES
59

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.
NBy-62225

b. PROJECT NO.
Y-F015-01-04-003

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
4074

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
CR 68.008

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this Document is Unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Naval Civil Engineering Laboratory
Port Hueneme, California 93041

13. ABSTRACT

To develop an embedment anchor to hold at 200 times its own weight of 25 lbs. extends the art of deep anchorings at small cost if a ballistic anchor containing a reciprocating mechanism can be materialized. Three general concepts are merged in one device: (1) about half the ultra high pressure energy released from a powder charge is used for ballistic penetration of the sea bottom. (2) a fraction of the balance of this energy is trapped at high working pressure and deepens the penetration by driving a simple, short-lived, reciprocating machine which executes less than 1000 cycles. (3) depletion of the trapped high pressure is finally downward at low pressure from the nose of the anchor so as to transport away bottom material which has been loosened by the action of the machine.

All main components are identified and dimensions are chosen to make these concepts compatible, and lead to a metal weight slightly in excess of the 25 lbs. goal. Performance of the embedment depends on details of the interaction between the anchor and local sea bottom and must be development tested. The mechanism with a very short-service life stroke should be inexpensive, but high temperature, high pressure seals for the brief duty are difficult and not known to be feasible.

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Embedment Anchor						
Pulse-Jet Anchor						
Reciprocating Anchor						
Explosive Anchor						
Reactive Anchor						
Ballistic & Mechanical Anchor						
Lightweight Explosive Anchor						
Self-valued Reciprocater						
Staged pressure containment						
Anharmonic Osicillator						
Short-lived Machine						
Expendable Mechanism						
Powder-driven Machine						
Thermo-mechanical Anchor						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
____."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
____."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

Unclassified
Security Classification